J Prod Anal (2010) 33:225–240
DOI 10.1007/s11123-009-0150-x

Sources of growth in Indonesian agriculture

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Published online: 16 September 2009

Abstract Indonesia sustained an average increase in agricultural output of 3.6% per year between 1961 and 2006, resulting in a more than fivefold increase in real output. This paper constructs Tornqvist-Thiel indices of agricultural outputs, inputs and total factor productivity (TFP) to examine the sources of growth in Indonesian agriculture over this period. The paper extends previous work on measuring productivity change in Indonesian agriculture by assembling more complete data on cropland and expanding the commodity coverage to include cultured fisheries in addition to crops and livestock. It also accounts for the contribution of the spread of rural education and literacy to agricultural growth. Results show that Indonesia pursued both agricultural intensification to raise yield, especially for food crops, and extensification to expand crop area and absorb more labor. Productivity growth accelerated in the 1970s and 1980s but stagnated in the 1990s once "Green Revolution" food crop varieties had become widely adopted. TFP growth resumed in the early 2000s led by diversification into non-staple commodities such as tropical perennials, horticulture, livestock and aquaculture. Agricultural extensification continued to be an important source of growth in many of parts of the archipelago where previously forested areas were converted to cropland. Human capital deepening, in the form of the spread of literacy and education in the farm labor force, made a modest but sustained contribution to agricultural productivity growth.

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Keywords Agricultural development · Growth accounting · Human capital · Total factor productivity · Tornqvist-Thiel index

JEL Classification Q10 · O47

1 Introduction

During the latter half of the twentieth century, rising output per hectare replaced expansion of crop land as the predominant source of agricultural growth in most of the world (Hayami and Ruttan 1985). This transition from agricultural extensification to intensification was particularly noticeable in Asia, where population density is relatively high and land scarcity acute. Indonesia is something of a special case, possessing both very densely populated, land scarce agriculture on Java, and relatively land-abundant agriculture on the large outer islands of Sumatra, Kalimantan, Sulawesi and Papua. The country achieved considerable success in agriculture during the 1970s and 1980s through the diffusion of high-yielding varieties of food crops, although this source of growth appeared to stagnate by the early 1990s (Fuglie 2004). Meanwhile, land devoted to agriculture continued to expand, with virtually all new cropland coming from Indonesia's outer islands, and principally for tropical perennials like oil palm and cocoa. In this paper, I examine the sources of agricultural growth in Indonesia over the 45 years from 1961 to 2006. I use a growth accounting method to examine how resource expansion, technological improvements, commodity diversification and human capital contributed to increasing real agricultural output.

The approach used in this paper builds on Fuglie (2004) who was the first to develop a Tornqvist-Thiel index of total factor productivity (TFP) for Indonesian agriculture. The present work expands commodity coverage to include cultured fisheries in addition to crops and livestock. Cultured fisheries are an increasingly important component of agriculture in many Asian countries and compete directly with crops and livestock for land, labor, feed and other resources, but have been largely ignored in assessments of agricultural productivity. In addition, this work includes improved data on agricultural cropland with more complete coverage of land planted to tropical perennials. Finally, the paper develops a measure of labor force quality as a factor in production. In many developing countries in Asia the rate of growth in the agricultural labor force has sharply declined or turned negative over the past several decades. However, labor force quality, in the form of the spread of literacy and universal primary education, has improved. Jamison and Lau (1982) compiled ample micro-level evidence to demonstrate the link between farmer education and agricultural productivity in developing countries; the present study accounts for the contribution of improvements in farmer education to productivity growth at the sector-level.

The Tornqvist-Thiel indexes of output, input and productivity are measures of changes in the real economy and avoid the index number bias arising from the use of fixed weights in input and output aggregation. Some previous studies of agricultural productivity in Indonesia have used agricultural Gross Domestic Product (GDP) as a measure of output (van der Eng 1996; Mundlak et al. 2004), but GDP confounds quantity and price effects on output growth and thus may not reflect true changes in productivity. Other studies have estimated Malmquist TFP indexes for Indonesia using the Food and Agriculture Organization's (FAO) agricultural output index and input quantity data (Arnade 1998; Suhariyanto 2001; Coelli and Rao 2005). However, the FAO output measure is a Laspeyres index using a fixed set of international prices as weights to aggregate commodities and may result in biases if there are significant changes in relative prices or commodity mix over time (Fan and Zhang 2002). Moreover, the Malmquist index measure of agricultural TFP is sensitive to the dimensionality issue (e.g. the number of countries and input–output quantities included in the analysis) and may give implausible results (Lusigi and Thirtle 1997).

For this study I develop time series of output and input quantity and prices and use moving averages of revenue and cost shares to aggregate outputs and inputs, respectively. Agricultural output is composed of 75 crop, animal and fish commodities. The agricultural input index consists of 42 types of land, labor, capital and intermediate inputs used in crop, livestock and aquaculture production. The Tornqvist-Thiel TFP index is given by the ratio of output to input, and thus TFP rises when output growth exceeds the growth in inputs. TFP is the residual component of growth after accounting for changes in factor inputs. It can be interpreted as a measure of the gain in efficiency with which inputs are used, including technological progress.

2 Methodology

Productivity statistics compare changes in outputs to inputs in order to assess the performance of a sector. Two major measures of productivity are partial and multifactor productivity indices. Partial productivity relates output to a single input. These measures, such as output per worker or output per hectare of cropland, are useful for indicating factor-saving biases in technical change but are likely to overstate the overall improvement in productivity because they do not account for changes in other input use. For example, rising output per worker may follow from additions to the capital stock and higher crop yield may be due to more application of fertilizer. For this reason, a measure of total factor productivity (TFP) relating output to all of the inputs used in production gives a superior indicator of a sector's efficiency than statistics on partial productivity.

I measure agricultural TFP as the ratio of total output to total inputs of the sector. Essentially, therefore, TFP measures the average product of all inputs. Let total output be given by Y and total inputs by X. Then TFP is simply:

$$\mathrm{TFP} = {}^{Y}\!/_{X}. \tag{1}$$

Changes in TFP over time are found by comparing the rate of change in total output with the rate of change in total input. Expressed as logarithms, changes in Eq. 1 over time can be written as:

$$\frac{d\ln(\mathrm{TFP})}{dt} = \frac{d\ln(Y)}{dt} - \frac{d\ln(X)}{dt}. \tag{2}$$

In agriculture, output is a composed of multiple commodities produced by multiple inputs, so Y and X are vectors. Chambers (1988) shows that under the assumptions that (i) producers maximize profits so that output elasticities equal input shares in total cost and (ii) markets are in long-run competitive equilibrium so that total revenue equal total cost, then Eq. 2 can be written as:

$$\ln\left(\frac{\mathrm{TFP}_t}{\mathrm{TFP}_{t-1}}\right) = \sum_i R_i \ln\left(\frac{Y_{i,t}}{Y_{i,t-1}}\right) - \sum_j S_j \ln\left(\frac{X_{j,t}}{X_{j,t-1}}\right), \tag{3}$$

where R_i is the revenue share of the ith output and S_j is the cost-share of the jth input. Output growth is estimated by summing over the output growth rates for each commodity after multiplying each by its revenue share. Similarly, input growth is found by summing the growth rate of each input, weighting each by its cost share. TFP growth is just the different between the growth in aggregate output and aggregate input. A discrete time approximation of the Divisia index given in Eq. 3 is the Tornqvist-Thiel productivity index:

$$\ln\left(\frac{\mathrm{TFP}_t}{\mathrm{TFP}_{t-1}}\right) = \sum_i \frac{(R_{i,t}+R_{i,t-1})}{2}\ln\left(\frac{Y_{i,t}}{Y_{i,t-1}}\right) - \sum_j \frac{(S_{j,t}+S_{j,t-1})}{2}\ln\left(\frac{X_{j,t}}{X_{j,t-1}}\right). \quad (4)$$

Chambers (1988) shows that the Tornqvist-Thiel TFP index in Eq. 4 can be derived from a translog production function that exhibits Hicks-neutral technical change. Because the translog is a flexible function form, the Tornqvist-Thiel index provides a superior measure of productivity change than alternatives that assume a more restrictive production relationship.

A further modification of the index construction is to account for changes in input quality. Over time, investments in education will raise the quality of the farm labor force and improvements in irrigation and drainage the quality of land. Technical improvements may also raise the quality of farm machinery, chemicals and other inputs, sometimes referred to as factor-augmenting technical change (Hayami and Ruttan 1985). One way to account for changes in input quality is to disaggregate inputs into finer detail, such as cropland into irrigated and non-irrigated areas, or machinery into its various components, such as tractors of a certain size, harvesters, water pumps, etc. A second way is to construct an index of input quality and adjust the quantity measure accordingly. I combine these approaches by disaggregating inputs into as many subcategories as possible to account for compositional (quality) changes over time. In the case of labor, I construct a labor quality index based on the average schooling level achievement of the rural male and female labor force. Specifically, let $\mathrm{L}_t^* = \lambda_t\ \mathrm{L}_t$, where L_t^* is the observed number of work-days in year t by the agricultural labor force, λ_t is a quality indictor of educational achievement, and L_t is the labor force measured in constant-quality units. Using a Mincerian-type earnings function, the labor force quality indicator is specified as:

$$\lambda_t = \exp(\alpha s_t) \quad (5)$$

where s_t is the average educational level of the farm labor force and α is the percent increase in labor productivity due to education (i.e., $d\ln(\lambda_t)/ds_t = \alpha$). This allows us to decompose the effects of changes in labor quantity and quality on agricultural growth over time. The Mincerian interpretation of Eq. 5 is that s is the average number of years of schooling and α is the rate of return to an additional year of schooling (Psacharopoulos and Patrinos 2004).

With these quality adjustments, the first term on the right-hand-side of Eq. 4 is the Tornqvist-Thiel index of aggregate output change and the second term is the Tornqvist-Thiel index of aggregate input change. The indices can be calculated directly from data on period prices and quantities for each output and input included in the aggregation. The procedure is to take the exponent of a right-hand-side term in Eq. 4 and chaining it to derive the index values. For example, suppose the first period is year 1. Beginning with a base value for the index of 100, the value of the output index for year 2 is:

$$I_2^Y = 100 \times \exp\left\{\sum_i \frac{(R_{i,1}+R_{i,2})}{2}\ln\left(\frac{Y_{i,2}}{Y_{i,1}}\right)\right\}. \quad (6)$$

Similarly, the value of this index in year 3 is given by:

$$I_3^Y = I_2^Y \times \exp\left\{\sum_i \frac{(R_{i,2}+R_{i,3})}{2}\ln\left(\frac{Y_{i,3}}{Y_{i,2}}\right)\right\}. \quad (7)$$

The input index is constructed in a similar fashion using the time series of inputs and their factor shares. Once the index series for total output and total input have been constructed, the TFP index is derived by taking the ratio of the two and multiplying by 100:

$$I_t^{TFP} = 100 \times \frac{I_t^Y}{I_t^X}. \quad (8)$$

To summarize, the theory underpinning the Tornqvist-Thiel TFP productivity index assumes that producers maximize profits and that markets are in long-run competitive equilibrium (where technology exhibits constant returns to scale) so that the elasticity of output with respect to each input is equal to its factor share and total revenue equals total cost. If the underlying production function is translog, then the Tornqvist-Thiel TFP index is an exact representation of Hicks-neutral technical change. The translog is referred to by Diewert (1976) as a flexible functional form because it is a second-order approximation of an unknown underlying production function. Thus, the Tornqvist-Thiel index method places relatively few restrictions on the form of the production technology but relies on rather strong (but not unusual) behavioral restrictions in order to be interpreted as a measure of productivity change.

3 Data

Recent improvements in the quality and coverage of data on agricultural production and input use have facilitated measurement of agricultural productivity change in Indonesia. Van der Eng (1996) developed long-term series for outputs and prices of major crop and livestock commodities as well as land and labor inputs. In particular, van der Eng provides superior estimates of cropland compared with

FAO estimates of agricultural land in Indonesia, which appear to substantially underestimate historical land use changes for this country (Fuglie 2004). The present study extends and improves upon these data by adding outputs and inputs from cultured fisheries (aquaculture) to obtain a more complete coverage of output of the agricultural sector,[1] uses a more complete measure of land planted to estate crops, and accounts for the contribution of human capital investments to productivity growth. In the remainder of the paper, data sources are represented by 'FAO' for the FAOSTAT series (FAO 2009), 'BPS' for the Indonesian Central Statistics Agency, 'MOA' for sources from the Ministry of Agriculture (MOA 2009) and 'VDE' for data series reported in van der Eng (1996).

3.1 Crop, livestock and aquaculture output

FAO production data are used to measure outputs of food, horticultural, estate crops, meat, milk, eggs and animal fibers since 1961.[2] These are measured in metric tons of gross production. The series include 55 crop commodities and 19 livestock commodities. For cultured fisheries, I use estimates of production from brackish and freshwater ponds, cages and paddy fields from BPSa. These estimates are given in metric tons and do not distinguish by species. However, the FIGIS (2009) dataset breaks down cultured fisheries production by species (diadromas, pelagic, demersal, crustacean, mollusks, cephalopods, other marine fishes and other freshwater fishes).[3]

3.2 Commodity prices

Ideally we would like to have data on actual prices received by farmers for their commodities but the only commodity price data with sufficient coverage available for Indonesia are wholesale prices. The FAO 'producer price' series (available for most commodities since the mid-1960s) and VDE's 'rural bazaar prices' for selected crops actually appear to be urban wholesale prices as they closely track the Jakarta wholesale commodity prices published by BPSa. For this study I used BPSa annual price series for 14 commodities (major food and estate crops, beef and eggs) and FAO producer prices for horticultural crops and minor estate crops. Supplemental price data for some estate crops (cane sugar, kapok fiber, and ginger) are from MOA. VDE price data were used to fill in for gaps in the series, especially for the early 1960s. Fish prices for the eight categories of fish outputs are export prices derived from FAO trade data.

For some commodities, consistent price series were established in Indonesia only in the late 1960s or early 1970s. For missing years, the average normalized price (commodity price relative to the price of rice) for the nearest five-year period for which price data were available were used to extend the series back to 1961. The relative prices were then used to construct revenue shares for those years.

To account for marketing margins between prices received by farmers at harvest and at wholesale, I assume an average marketing margin for all commodities of 20%. Mears (1981), in a comprehensive study of rice marketing in Indonesia, estimated marketing costs between farm and wholesale levels in the late 1970s to be between 15 and 25% of the farmgate price. While only one commodity, rice accounts for about half of agricultural output in Indonesia. For the purposes of forming the agricultural output index, this assumption about the marketing margin is innocuous since it does not affect the relative prices among commodities which are used to aggregate outputs. However, it will affect the cost share attributed to land, which is estimated as a residual after other costs are deducted from total revenue (see below).

3.3 Land in crops and ponds

Van der Eng (1996) provides estimates of irrigated crop land, area in terraced rice lands (*sawah*), area in garden and upland crops, and area in industrial or estate crops through 1992. More recent data on these series, including area in aquaculture, are available from BPSa. However, van der Eng's estimate of area planted to estate crops up to the late 1970s is substantially lower than recently available from the MOA. Van der Eng's estimates appear to include only

[1] Here and in the remainder of the paper I exclude the forestry and marine and inland capture fishery components of Indonesia's agricultural sector from the analysis. Forestry and capture fisheries in Indonesia are extractive industries that generally have not competed directly for resources used in crop, livestock and aquaculture production. However, there is likely to be growing competition in land use among agriculture, plantation forestry and natural forest conservation in the coming years, and this would likely be a fruitful area to explore in future work.

[2] I follow the Indonesian classification system for crop commodities whereby food crops (*palawija*) include rice, maize, cassava, soybean, mungbean and sweetpotato; horticultural or garden crops include other vegetables and fruits; and estate crops include oil palm, rubber, coconut, sugar, coffee, cocoa, tea, tobacco, fiber crops, nuts, spices and other specialty crops.

[3] FIGIS and BPSa define marine and fresh water fisheries differently but report nearly identical aggregate estimates of fish production for Indonesia (FIGIS includes harvest of aquatic animals, plants and corals in aggregate fisheries production while BPSa excludes these species). In terms of resource use, BPSa assigns all production from aquaculture (brackish or freshwater) to cultured fisheries while FIGIS allocates production to either marine fisheries (including brackish pond aquaculture) or inland fisheries (including cultured production and open water catches).

the harvested area for major estate crops and exclude area planted to immature trees and to minor estate crops. The new MOA data includes area planted to immature and non-producing trees of rubber, coconut, oil palm, tea, coffee, cocoa, kapok, clove, and other nut and spice perennials since 1967. On average, the area in immature trees accounted for about 30% to the total area planted to these crops. I estimate the area planted to perennials for the years 1961–1966 by applying this ratio to FAO data on area harvested for these crops in these years.

Since price series are unavailable for cropland and ponds, the annual cost share for agricultural land is estimated as the residual output revenue—the remainder of total output after paying for agricultural labor, fertilizer, machinery and animal services, as well as the 20% deduction for marketing costs and losses mentioned above. The annual growth rate in land is derived from a quality-adjusted aggregation of different land classes. I assign quality weights to each type of land based on the average gross value of output per hectare of resource relative to the lowest quality of land, or fields in upland crops (i.e., fields that have been cleared but have not been terraced, irrigated, or planted with trees). Letting the quality weight for uplands be 1.00, the weights for the other land classes are as follows: 4.00 for irrigated wetland rice, 2.0 for non-irrigated wetland rice, 1.50 for cropland planted to perennials, 2.00 for fresh water ponds, 1.00 for brackish water ponds, and 0.50 for paddy fisheries. In other words, irrigated rice land, which is usually double or triple cropped, has twice the annual value of non-irrigated but terraced rice fields, which in turn is about twice the value of non-irrigated upland fields. Land in estate crops, which have been augmented by tree plantings, has greater value than upland fields but less than terraced rice fields. One way to interpret these weights is that they reflect (relative) returns to investments in land improvement. Agricultural land with more improvements in the form of irrigation, terracing, tree planting, and pond structures are more productive than land without these features and are given a higher quality weight. The weight on paddy fisheries reflects the augmentation in resource value when fish are jointly produced with rice in paddy fields.

3.4 Agricultural labor, education and wages

Data on two categories of labor—adult male and adult female workers employed in agriculture—are available from FAO. Wages for male and female workers are average daily wage paid for crop weeding (BPSc 1993–2007). To find total annual labor costs, daily wages (in rice equivalents) are multiplied by 300 days worked per year for men and 250 days worked per year for women.

I adjust for improvements to labor quality by considering the average years of schooling of the agricultural labor force. To derive the effect of schooling on labor quality, I assume the increase in productivity from an additional year of schooling to be 7% for men and 8% for women, using Kawuryan's (1997, p. 218) estimate of the marginal private rate of return to primary schooling, who fitted data from the 1989 national labor force "SAKERNAS" survey to a Mincerian earnings function. Kano (2008) reports the share of the agricultural labor force with no schooling, incomplete primary, completed primary, incomplete secondary, completed secondary, and post-secondary education for 1971, 1980, 1990 and 2000, based on population censuses and SAKERNAS surveys. I estimated the average years of schooling for a worker in the agricultural labor force from these data by multiplying 0, 3, 6, 9, 12, and 15 years of schooling times the share of farm workers with these schooling levels, respectively. Thus, between 1971 and 2000, the average schooling of male agricultural workers increased from 2.60 years to 5.88 years and for women from 1.24 to 4.42 years. The rise in average schooling was the outcome of a national policy of universal primary education that was decreed in the 1970s (Kawuryan 1997).

3.5 Fertilizer and chemicals

Annual applications of chemical fertilizers (N, P_2O_5 and K_2O) are from FAO. Prices paid for fertilizer are from VDE, updated since 1996 using BPSb (1993–2007). From the early 1970s until 1999, chemical fertilizers were heavily subsidized in Indonesia, sometimes by as much as 50% of actual cost. This raises the question whether fertilizer inputs should be weighted by their social or private costs. Private costs (at the subsidized price) are used in this study to conform with the theory underpinning the index number approach to measuring productivity. However, despite rapid growth in fertilizer application during the last several decades, the share of fertilizer in total costs remained small. Even at the social cost of fertilizer, total (private and government) expenditure on fertilizer rarely exceeded 4% of the value of agricultural output.

Published data on chemical inputs in agriculture (insecticides, herbicides, fungicides, etc.) are fragmentary. FAO reports tons of active ingredients of fungicides, herbicides insecticides, and other chemicals consumed for 1990–1993 only. But these figures are substantially lower than those reported for 1980–1996 in Oudejans (1999) who obtained data from the agro-chemical industry. Based on Oudejan's figures and my estimate of aggregate agricultural revenue, it appears that pesticide costs did not exceed 0.5% factor share in any year up through 1996. Due to the incompleteness of pesticides data they are not included in the input aggregation.

3.6 Agricultural machinery

Agricultural machinery includes the number of tractors in use adjusted for size (BPSa 1993–2007). The agricultural machinery series are aggregated in terms of total horse power (hp) supplied, assuming the following values per machine: 12 hp per two-wheel tractor and 20, 33 and 50 hp per small, medium and large four-wheel tractors, respectively. Power services are assumed to be constant over the life span of the machine (i.e., I assume a one-hoss-shay depreciation schedule for capital services). The annual cost of capital services is determined by estimating an annual service flow per hp and multiplying this by the total stock of hp of farm tractors. To estimate the annual service flow per hp, I use FAO data for the average import price for tractors and then amortize this price assuming a 10-year life span and a 10% discount rate. I then divide this cost by the average hp/tractor in service for each year to derive the annual depreciation of 1 hp of capital services. I then double this to account for fuel and repair costs.

3.7 Livestock and poultry

Livestock and poultry contribute to agriculture in several ways. In addition to yielding meat, hides, milk and eggs, they provide power, fertilizer, offspring, and serve as a store of wealth. I measure animal inputs as the annual stocks of buffalo, beef cattle, dairy cows, horses, pigs, small ruminants and poultry. Data on animal stocks are from FAO. The relevant price weight for an animal input is the value of services from that animal in a given year rather than its stock value. This is important for animals that provide services for several years, such as large ruminants. Prices for live animals are FAO import values for cattle, buffalo, horses, and sheep and export values for pigs and poultry. To derive annual service flows for long-lived species (large ruminants), the purchase prices are amortized over three years using a 10% discount rate.

3.8 Feed and seed

Fuglie (2004) subtracted feed and seed inputs from output and used a “net output” measure for crops and livestock to construct his output, input and productivity series for Indonesian agriculture. In this study, I include feed and seed in the input aggregation and use gross outputs for the output series. While this should have little or no effect on the estimate of TFP, it will change both the measured output and aggregate input to be consistent with the method used by the USDA for measuring agricultural TFP (Ball et al. 1997). Moreover, I have developed a more complete accounting of feed inputs used in Indonesian livestock production by combining data from the FAO commodity balance sheets and the USDA’s Production Supply and Distribution (PSD) database (USDA 2009). USDA data, which primarily measure raw materials used by commercial feed manufacturers, are used for feed from domestic and imported maize, by-products from wheat milling, and meal by-products from soybean, oil palm and copra and fish processing. FAO data are used for other sources of feed, and include by-products from rice milling (bran and broken rice), molasses from sugar processing, tuber crops, meat meal, and milk fed to young animals. Feed prices are domestic commodity prices for rice, maize and milk, FAO export values for rice bran, dried cassava, copra meal, oil palm meal and molasses, and FAO import values for soymeal and fishmeal. Seed prices are set at 1.5 times the corresponding domestic commodity prices.

4 Results

4.1 Agricultural output

Table 1 shows the changing levels and composition of real crop, animal and aquaculture output in Indonesia since 1961. The first three columns of numbers in the Table report average yearly output levels during the first half of each decade in terms of ‘rice equivalents’, where commodities are valued and aggregated by their current price relative to the price of rice. The next four columns show average annual growth rates for major commodity groups during 1961–1980, 1981–2000, 2001–2006, and over the entire 1961–2006 period. Between the early 1960s and early 2000s, total annual output of crops, livestock and cultured fish increased from 27.5 million tons to 138.2 million tons. The average annual growth rate was 3.6% when measured in terms of ‘rice equivalents’ although the growth rate appeared to be slowing over time. Growth was very robust during the “Green Revolution” period (1960s and 1970s) when high-yielding rice varieties were widely adopted. The growth rate in food crop output slowed appreciably in the 1990s and early 2000s, while growth in horticulture, animal products and aquaculture remained strong. Among estate crops, oil palm and cacao production expanded rapidly after 1980 while sugar cane and coffee production stagnated.

The bottom rows of Table 1 show agricultural output in constant Rupiah and U.S. dollar values. The gross value of agricultural output grew slightly faster than the quantity output measured in terms of rice equivalents. Growth in output value was especially robust in the early 2000s, where gross revenue grew by 5.2% per annum compared with real quantity growth of only 1.8%. The difference reflects a rise in agricultural prices relative to the general rate of inflation, or improving terms of trade for agricultural producers. The value of agricultural output in 2006

Table 1 Level and composition of agricultural output in Indonesia

	Average annual production (million tons of rice equivalents)			Average annual growth rate (%)			
	1961–1965	1981–1985	2001–2005	1961–1980	1981–1900	2001–2006	1961–2006
Food crops	16.3	45.0	67.0	4.5	2.8	0.5	3.2
Rice, paddy	12.4	35.8	52.5				
Maize	1.1	2.6	7.1				
Groundnut	0.5	2.5	3.5				
Cassava	1.5	2.5	2.5				
Other food crops	0.9	1.7	1.4				
Horticultural crops	3.7	8.9	21.6	3.9	4.2	4.5	4.1
Vegetables	1.9	4.4	9.4				
Fruits	1.8	4.5	12.2				
Estate crops	5.2	15.4	31.3	5.5	2.7	1.9	3.8
Oil palm	0.1	0.5	8.8				
Coconut	1.3	4.8	6.5				
Rubber	1.6	2.3	5.5				
Sugar cane	0.4	2.9	2.9				
Cacao	0.0	0.1	1.8				
Coffee	0.3	1.1	1.3				
Other estate crops	1.6	3.8	4.5				
Animal products and aquaculture	2.2	9.2	18.3	6.8	3.0	3.6	4.7
Poultry meat and eggs	0.7	3.0	7.7				
Beef	0.5	2.3	4.7				
Aquaculture	0.2	0.4	1.3				
Other meat, milk and hides	0.9	3.5	4.6				
Crops, animal and aquaculture output	27.5	78.6	138.2	4.9	3.0	1.8	3.6
Agricultural gross revenue[a] (constant 2006 trillion Rupiah)	78.8	187.9	390.3	4.0	4.1	5.2	4.2
Agricultural gross revenue[a] (constant 2006 billion US$)	11.1	47.2	38.1	8.5	−2.5	9.1	3.7

Quantities are reported as millions of tons of “rice equivalents” by normalizing prices on the current price of rice before aggregation

Source: Authors calculations. See text for data sources

[a] Gross revenue is deflated by the Indonesian Consumer Price Index (BPSa 1993–2007). To convert to US$, current revenues are converted at the average annual exchange rate (Bank of Indonesia) and deflated by the United States Consumer Price Index (Economic Report of the President 2009)

US$ was highly variable due to exchange rate fluctuations. The dollar value of output actually declined during 1981–2000 due to the sharp devaluation of the Rupiah during the Asian financial crisis of the late 1990s. For the purposes of productivity analysis, however, our interest lies in real quantity changes and not gross output value or value-added which confound real output (quantity) changes and terms of trade effects.

4.2 Agricultural input use

In the latter half of the twentieth century Indonesia added significant amounts of land, labor and other inputs to agriculture (Table 2). Cropland expanded by an average of 1.4% per year during 1961–2006 and was still growing by more than 1% pear year in the mid 2000s. Virtually all of the expansion occurred outside the densely populated island of Java, especially on Kalimantan, Sumatra and Sulawesi (van der Eng 1996; MOA 2009). Nationally, agricultural cropland expanded to 36 million hectares by the early 2000s. Irrigation had been extended to 4.8 million hectares and covered about 60% of the wetland rice (*sawah)* area. Land resources devoted to aquaculture (brackish and fresh water ponds) grew from 0.3 million hectares to 0.7 million hectares between 1961–1965 and 2001–2005, with expansion of ponds accelerating over time. But the largest increase in cropland was for estate crops. The new estimates of area planted (including area in immature trees) show that

Table 2 Inputs used in Indonesian agriculture

	Average annual quantity			Average annual growth rate (%)			
	1961–1965	1981–1985	2000–2005	1961–1980	1981–2000	2001–2006	1961–2006
Total cropland (million hectares)	20.48	27.15	35.90	1.0	1.7	1.4	1.4
Sawah cropland (million hectares)[a]	5.59	7.23	7.90	1.4	0.5	0.2	0.8
Irrigated cropland (million hectares)	2.42	3.31	4.78	1.4	2.3	−0.4	1.6
Estate cropland (million hectares)[b]	4.60	8.85	17.15	2.8	3.5	2.7	3.1
Other cropland (million hectares)	10.28	11.07	10.84	−0.3	0.7	0.1	0.2
Area in fish ponds (million hectares)	0.29	0.35	0.71	0.5	3.6	4.3	2.4
Agricultural labor force (million persons)[c]	28.64	37.67	50.72	1.1	1.8	0.6	1.4
Fertilizer (million tons)	0.12	1.67	3.21	4.6	6.3	3.4	5.2
Feed (million tons)	1.58	5.37	15.06	10.4	2.0	6.3	6.1
Tractor power (million horsepower)	0.05	0.19	1.35	0.0	0.0	0.0	0.0
Animals (million head of cattle equivalent)[d]	14.00	18.41	33.15	0.4	0.9	1.7	0.8
Cropland/worker (hectare/person-year)	0.72	0.72	0.71	−0.1	−0.1	0.7	0.0
Machinery/worker (HP/1000 person-years)	1.77	5.09	26.61	−1.1	−1.8	−0.6	−1.4
Fertilizer/cropland (kg/hectare)	5.92	61.36	89.47	3.6	4.6	2.1	3.8
Feed/animal (kg/head of cattle)	112.67	291.68	454.21	10.0	1.1	4.6	5.3

Source: Author's calculations. See text for data sources

[a] *Sawah,* also called "wetland," is land that has been terraced for growing paddy rice, but may also be planted to non-rice crops during the dry season. Irrigated cropland is a subset of *Sawah*

[b] Includes area planted to immature trees

[c] The agricultural labor force is the FAO estimate of the number of economically active persons (male and female) in agriculture

[d] Animal stock is measured in units of "cattle equivalents" using the weights for each species suggested by Hayami and Ruttan (1985)

estate cropland grew from 4.6 million hectares in the early 1960s to over 18 million hectares by 2006. By the late 1990s, oil palm had replaced rubber and coconuts as the dominant estate crop and by 2006 accounted for about one-third of the total estate cropland. Other important estate crops include cocoa, coffee, sugar cane, cloves and cashews. About 14 million out of the total of 18 million hectares in estate crops were held by small-holders and the rest by large private and state-owned plantation companies (MOA 2009).

FAO reports that the number of persons employed in agriculture in Indonesia grew from 28 million to 51 million persons over 1961–2006 and was still growing by about 0.6% per year in the early 2000s. However, many of these persons only work part-time in farming, earning a large share of their household income from non-farm activities, and it is difficult to gauge trends in actual time spent in farming. In densely populated Java, time spent in farming per agricultural worker probably declined as census data has shown that the share of non-farm income in the total income of farm households has risen (Booth, 2002). However, outside of Java, area in crops expanded more rapidly than the agricultural labor force so area farmed per worker rose even though mechanization levels remained very low (van der Eng 1996). In these regions, average time spent farming per worker may have increased. This is where most of the expansion in estate crop production occurred, and, unlike annual crops were labor demand tends to be highly seasonal, labor required in tree crop production is often more evenly spaced throughout the year. Oil palm bunches, for example, ripen continuously throughout the year and need to be selected and picked manually when ripe. It is difficult to say how per capita labor allocated to agriculture may have trended nationally, but it is worth noting that cropland per capita grew, from about 0.8 ha/persons in 1960–1965 to 1.1 ha/person in 2000–2005 (Table 2). Because the labor force data does not adjust for hours worked per capita, changes in hours worked would influence growth in TFP: an increase in hours worked per capita would likely increase measured TFP, while a decrease in hours worked per capita would reduce TFP.

Growth in manufactured inputs used in agriculture, such as fertilizer, machinery and animal feed, was rapid but started from an almost negligible level. Fertilizer use grew by 11%/year during 1961–1980, when high-yielding, fertilizer responsive varieties of rice were widely adopted and the government introduced subsidies for fertilizers and pesticides. The level of fertilizer subsidy was as much as 50% from the mid-1970s to the mid-1980s, but then gradually declined and ended in 1999. Average fertilizer application reached 80 kg/ha by the early 2000s but was still low by international or even Asian standards (Mundlak et al. 2004). Adoption of farm machinery accelerated after 1981, especially for two-wheel walking tractors that began to replace draft animals in tillage operations, although the ratio of tractor horsepower to workers remained very low compared with other Asian countries like China and India. The rapid increase in feed consumption per animal reflects a rise in confinement-based animal production systems and greater availability of wastes from agricultural processing industries for use as animal feed. Manufactured animal feed is especially important in poultry, dairy and aquaculture production.

4.2.1 *Tornqvist-Thiel indices of agricultural output, input and TFP*

Indices showing the changing composition of outputs in Indonesian agriculture are given in Table 3. Total output is decomposed into food crops, horticultural crops, estate crops, and animal products and fish. While food crop production was 4.11 times higher in 2006 compared with 1961, its revenue share declined from about 60–50% over this period. The decline in importance in food crops was due especially to the more rapid growth in horticulture, animals and fish production. The revenue share of horticulture rose from 13 to 16% and the revenue share of animal and fish from 8 to 13% over the entire period. The shift in production away from staple food crops to other commodities occurred mainly during the 1990s and early 2000s.

Table 4 shows the trends in utilization and cost shares for major input categories (land, labor, animals, machinery, and intermediate inputs). The measure of agricultural land (which includes quality improvements such as irrigation, terracing, fish ponds and tree planting) nearly doubled over 1961–2006. Since payments to land are measured as the residual from revenue after paying for other inputs, the land cost share varies from year to year with the variability in output. The factor share of land during 1961–2006 average 26% and showed no clear trend upward or downward over time. This factor share is similar to what Evenson et al. (1999) estimated for India. Using agricultural census information between 1956 and 1987, they found that land rental payments for irrigated and rainfed cropland in India ranged from 0.17 to 0.31 of total costs. Fan and Zhang (2002) found that the factor share of cropland and irrigation in China averaged 21% of total revenue from the 1960s through the mid-1990s. Thus, the factor share for land measured for Indonesia is within the range of estimates for other major developing countries in Asia.

The input accounting for the largest portion of agricultural costs is labor, with an average factor share of 42%. The number of persons employed in agriculture grew rapidly in the 1970s and 1980s but then leveled off and will probably start declining before the end of the current decade. The decline in the growth of the farm labor force reflects both a fall in the population growth rate and migration of labor to non-farm sectors. There was also a shift in the composition of the agricultural labor force to include a greater proportion of women and workers with formal schooling. In the next section we return to the issue of labor quality and estimate the contribution of increased education of the farm population to agricultural growth.

The factor share of livestock services declined sharply from about one-third of total costs in the 1960s to only about 12% of total costs by the early 2000s. This trend reflects in part a substitution of tractor power for bullock power (although animal traction still remains more important than tractors for land cultivation) and the growth of confinement-based animal production systems, especially poultry, that are short-lived and rely on prepared feed rather than pasture land. As livestock production shifts to confinement-based systems, intermediate inputs like feed substitute for fixed inputs like animal stocks and pastures. However, I have not included pastures in the land variable because of the wide discrepancies in available data. For example, for 2003 FAO reports 11.2 million hectares in permanent pastures while BPSa reports 2.4 million hectares in pasture meadows. Neither series shows much change over time.

Agricultural tractor capital grew rapidly from very low initial levels. In 1961 there were only about 1,000 tractors in service (nearly all of them two-wheel walking tractors), but by the mid-2000s there were over 100,000 two-wheel tractors and 5,000 four-wheel tractors in use (BPSa 1993–2007). Nonetheless, tractor horsepower per worker was still very low relative to other Asian developing countries like China, the Philippines and India, and the cost share of machinery capital averaged only about 1% over the period. The cost share of tractor services rose in the 1970s but then fell as the estimated price of these services declined in real terms. However, the price of tractor services is derived from tractor import prices, and the observed decline in import prices could simply reflect changes in the quality of tractor imports (importation of smaller tractors, for example). The measurement of machinery capital and costs remains incomplete at this time, and would benefit from a more complete accounting of machines used in farming and farm-level data on the cost of machinery services.

The cost share of intermediate inputs (seed, fertilizer and animal feed) doubled from 7% in the 1960s to 14% in the early 2000s. The use of industrial inputs in agriculture typically rises with the application of modern technology. It also reflects a lowering of the relative cost of these inputs as the manufacturing sector of the economy grows and industrial inputs can be sourced domestically. By the early

Table 3 Quantity indices for agricultural outputs

	Food crops		Horticultural crops		Estate crops		Animals and aquaculture	
	Index	Rev. share	Index	Rev. share	Index	Rev. share	Index	Rev. share
1961	100	0.60	100	0.13	100	0.19	100	0.08
1962	109	0.64	101	0.13	101	0.15	103	0.08
1963	97	0.56	108	0.13	105	0.23	103	0.08
1964	107	0.60	110	0.14	101	0.18	107	0.08
1965	107	0.58	116	0.14	104	0.19	108	0.08
1966	114	0.57	118	0.12	104	0.24	107	0.08
1967	107	0.61	120	0.09	102	0.22	109	0.08
1968	136	0.64	122	0.09	107	0.21	109	0.06
1969	138	0.53	129	0.13	113	0.27	112	0.07
1970	148	0.56	145	0.14	116	0.23	122	0.07
1971	153	0.53	144	0.13	118	0.25	128	0.08
1972	147	0.54	153	0.14	127	0.24	134	0.08
1973	166	0.55	168	0.14	125	0.25	142	0.07
1974	172	0.50	167	0.13	130	0.28	152	0.09
1975	172	0.58	155	0.13	133	0.19	158	0.10
1976	174	0.58	130	0.10	142	0.23	166	0.10
1977	179	0.54	150	0.11	148	0.25	171	0.11
1978	197	0.55	142	0.09	150	0.25	176	0.11
1979	200	0.54	153	0.11	161	0.25	192	0.11
1980	223	0.56	168	0.11	167	0.22	211	0.12
1981	242	0.56	179	0.12	173	0.20	226	0.12
1982	239	0.58	174	0.12	176	0.18	236	0.12
1983	257	0.59	192	0.11	183	0.20	267	0.11
1984	280	0.57	216	0.11	193	0.21	287	0.11
1985	282	0.56	223	0.12	210	0.20	309	0.12
1986	297	0.56	266	0.13	219	0.18	337	0.13
1987	294	0.55	266	0.11	234	0.21	350	0.13
1988	313	0.56	267	0.10	243	0.21	368	0.13
1989	332	0.56	273	0.11	246	0.19	391	0.14
1990	337	0.57	284	0.11	271	0.18	419	0.15
1991	334	0.58	303	0.11	287	0.18	445	0.13
1992	366	0.58	325	0.11	296	0.18	482	0.13
1993	358	0.55	320	0.12	313	0.18	527	0.15
1994	346	0.55	359	0.12	318	0.19	558	0.14
1995	368	0.54	512	0.15	325	0.19	549	0.12
1996	383	0.55	442	0.14	327	0.18	594	0.14
1997	366	0.54	401	0.15	325	0.17	592	0.14
1998	369	0.60	386	0.10	345	0.21	503	0.09
1999	376	0.56	419	0.11	353	0.22	498	0.11
2000	384	0.54	416	0.14	370	0.21	544	0.12
2001	373	0.51	433	0.15	406	0.22	577	0.12
2002	379	0.50	487	0.15	439	0.22	635	0.13
2003	392	0.49	578	0.16	468	0.22	679	0.13
2004	407	0.47	613	0.16	485	0.24	731	0.14
2005	412	0.46	621	0.17	526	0.24	685	0.13
2006	411	0.50	672	0.16	536	0.21	758	0.13

Table 3 continued

	Food crops		Horticultural crops		Estate crops		Animals and aquaculture	
	Index	Rev. share	Index	Rev. share	Index	Rev. share	Index	Rev. share
Average growth rates in the indices (%/year) and average revenue shares over the period								
1961–1970	4.37	0.59	4.12	0.12	1.64	0.21	2.21	0.08
1971–1980	4.07	0.54	1.51	0.12	3.66	0.24	5.48	0.10
1981–1990	4.15	0.57	5.23	0.11	4.83	0.19	6.86	0.13
1991–2000	1.30	0.56	3.81	0.12	3.11	0.19	2.61	0.13
2001–2006	1.14	0.49	8.00	0.16	6.18	0.22	5.53	0.13
1961–2006	3.14	0.55	4.23	0.12	3.73	0.21	4.50	0.11

Source: Author's estimates

2000s, this was the fastest growing component of agricultural inputs.

Indices for aggregate agricultural outputs, aggregate inputs and total factor productivity are shown in Table 5. The contribution of TFP to agricultural growth was relatively high during the 1960s and 1970s when "Green Revolution" crop varieties were widely adopted. During the 1980s TFP growth slowed but resource expansion accelerated to sustain overall growth of the sector. The low growth during the 1990s partly reflects stagnation in productivity and the impact of the Asian financial crisis in 1997–1998 when a sharp devaluation of the Indonesian currency caused the livestock sector, which was heavily depending on imported feed, to sharply contract. In recent years (2001–2006), TFP growth rose to levels as high as or higher than the peak years of the Green Revolution. A number of factors may have contributed to the return to high TFP growth: adoption of improved technology, diversification into high-valued commodities, and land expansion into tree crops. Tree crop expansion have contributed to measured TFP change by employing farm labor more fully over the year, since increases in labor supplied per worker are not accounted for in the input measurement.

4.3 Policy and productivity in Indonesia's agricultural development

In this section I divide 1961–2006 into four periods, each reflecting a different policy orientation toward agriculture, and compare the growth performance of the sector during each episode. The first period, 1961–1967, was the final years of the Sukarno era during which Indonesia suffered from macroeconomic and political instability. The second period (1968–1992), marks the early years of the "New Order" Suharto regime when food security was given precedence in economic development policy. Policies included large state subsidies for agricultural inputs, intervention in markets for food staples, and the promotion of "Green Revolution" crop varieties. Trade and fiscal imbalances in the mid-1980s caused economic policies to shift in favor of export-led manufacturing and subsidies for agriculture began to wane (Fuglie and Piggott, 2006). The economy severely contracted during the Asian Financial Crisis of 1997–1998 and national GDP did not return to pre-Crisis levels until 2002. I call the years from 1993 to 2001 a "stagnation" period for agriculture. The country emerged from the Crisis with a new "Reform" government and a more market-oriented agricultural policy. The fourth period, 2002 to the present, I call a "liberalization" period in which market forces played a larger role in allocating resources to and within the agricultural sector.

The sources of agricultural growth during each of the four periods are shown in Table 6. For each period I decompose growth into the share explained by resource expansion and the share due to productivity improvement. I further decompose growth in labor productivity (output per worker) into changes in land per worker, capital per worker, education and TFP.

During the first period of political and macroeconomic instability (1961–1967), agricultural output grew by only 1.24% per year, less than the rate of population growth. There were very few modern inputs employed in production and very little improvement to total factor productivity. The estate crop sector was still depressed following the nationalization of foreign-owned estates in 1957 (Booth 1988) and efforts to boost productivity of food crops suffered from a lack of appropriate new technologies (Jatileksono 1987).

The growth performance of agriculture improved significantly during the "Green Revolution" period (1968–1992). The priority given by the New Order government to food crop production was greatly aided by the recent development of high-yielding rice varieties by the International Rice Research Institute (IRRI) in the Philippines. These varieties were well-adapted to irrigated agriculture in tropical Southeast Asia and responded well to higher levels of fertilizer (Darwanto 1993). Using revenues from oil exports, the government promoted the new varieties and heavily subsidized fertilizers and irrigation development

Table 4 Quantity indices for agricultural inputs

	Land		Labor		Animals		Tractor machinery		Intermediate inputs	
	Index	Cost share	Index	Cost share	Index	Cost share	Index	Cost share	Index	Cost share
1961	100	0.25	100	0.30	100	0.36	100	0.00	100	0.08
1962	101	0.28	101	0.27	102	0.37	255	0.01	100	0.08
1963	102	0.27	101	0.30	102	0.34	429	0.01	99	0.07
1964	102	0.27	102	0.29	101	0.36	463	0.01	93	0.07
1965	103	0.07	102	0.49	107	0.37	510	0.02	102	0.06
1966	104	0.23	103	0.38	105	0.31	551	0.02	104	0.06
1967	105	0.13	104	0.43	100	0.35	593	0.03	105	0.07
1968	107	0.25	104	0.32	116	0.35	635	0.02	137	0.06
1969	108	0.28	105	0.42	100	0.22	676	0.02	126	0.06
1970	110	0.25	105	0.46	98	0.22	723	0.03	136	0.05
1971	111	0.26	107	0.45	101	0.20	765	0.04	150	0.05
1972	111	0.19	108	0.51	101	0.20	767	0.04	159	0.06
1973	113	0.33	110	0.41	95	0.17	769	0.03	186	0.06
1974	115	0.25	111	0.49	97	0.15	772	0.04	191	0.07
1975	116	0.14	112	0.53	95	0.17	780	0.02	194	0.13
1976	118	0.29	113	0.42	96	0.18	785	0.01	194	0.10
1977	121	0.40	115	0.43	98	0.08	817	0.01	215	0.09
1978	123	0.42	116	0.38	100	0.11	976	0.01	253	0.08
1979	127	0.36	117	0.36	103	0.18	978	0.01	276	0.08
1980	127	0.24	118	0.48	105	0.20	1,009	0.00	297	0.08
1981	132	0.23	121	0.48	108	0.18	1,080	0.00	370	0.10
1982	137	0.21	124	0.50	110	0.18	1,196	0.00	379	0.10
1983	143	0.27	127	0.44	133	0.19	1,201	0.00	406	0.10
1984	144	0.28	129	0.40	143	0.21	1,604	0.00	471	0.11
1985	139	0.24	132	0.44	151	0.21	1,744	0.00	491	0.11
1986	145	0.28	135	0.41	159	0.20	1,809	0.00	532	0.11
1987	159	0.21	137	0.43	159	0.25	1,971	0.00	593	0.12
1988	160	0.17	140	0.43	162	0.27	2,365	0.00	619	0.13
1989	165	0.16	143	0.45	168	0.28	2,738	0.00	646	0.11
1990	167	0.18	145	0.44	175	0.25	2,991	0.01	706	0.13
1991	169	0.27	147	0.43	183	0.17	3,576	0.01	729	0.13
1992	172	0.30	149	0.42	193	0.14	3,702	0.01	796	0.14
1993	175	0.21	150	0.46	192	0.17	4,670	0.01	845	0.14
1994	173	0.22	152	0.44	204	0.19	5,479	0.01	958	0.15
1995	177	0.31	153	0.38	208	0.16	5,880	0.01	1,042	0.14
1996	180	0.31	154	0.40	216	0.15	6,553	0.01	1,081	0.13
1997	182	0.28	155	0.42	212	0.15	7,389	0.01	996	0.14
1998	186	0.39	157	0.27	184	0.20	8,394	0.02	865	0.13
1999	185	0.46	158	0.28	175	0.12	8,160	0.01	918	0.12
2000	184	0.30	159	0.45	177	0.12	9,204	0.02	970	0.12
2001	187	0.26	160	0.44	181	0.15	9,376	0.02	1030	0.14
2002	187	0.29	160	0.44	199	0.12	9,555	0.01	1,114	0.12
2003	194	0.33	161	0.44	195	0.09	9,583	0.01	1,154	0.12
2004	189	0.30	161	0.43	192	0.10	9,698	0.01	1,223	0.16
2005	194	0.33	163	0.40	199	0.09	10,183	0.01	1,267	0.15
2006	197	0.23	162	0.46	200	0.15	9,862	0.01	1,296	0.15

Table 4 continued

	Land		Labor		Animals		Tractor machinery		Intermediate inputs	
	Index	Cost share	Index	Cost share	Index	Cost share	Index	Cost share	Index	Cost share
Average growth rates in the indices (%/year) and average cost shares over the period										
1961–1970	1.06	0.23	0.59	0.36	−0.24	0.33	21.98	0.02	3.39	0.07
1971–1980	1.44	0.29	1.16	0.45	0.70	0.16	3.34	0.02	7.85	0.08
1981–1990	2.72	0.22	2.05	0.44	5.13	0.22	10.86	0.00	8.65	0.11
1991–2000	0.98	0.30	0.89	0.40	0.07	0.16	11.24	0.01	3.17	0.13
2001–2006	1.17	0.29	0.33	0.44	2.04	0.12	1.15	0.01	4.83	0.14
1961–2006	1.51	0.26	1.07	0.42	1.53	0.20	10.20	0.01	5.69	0.10

Source: Author's estimates

(Jatileksono 1987). It also intervened in agricultural markets by restricting food imports and guaranteeing prices received by farmers (Timmer 2003). The New Order government also encouraged the expansion of cropland in sparsely populated regions of the country by subsidizing migration from Java and the planting of estate crops. One method was the "nucleus estate" scheme in which plantation companies, in exchange for state-backed financing and long-term leases to public land, were obliged to provide processing and other services to small-holders in the areas surrounding the large estates (Potter and Lee 1998). During this "Green Revolution" stage (1968–1992), agricultural output growth accelerated to 4.8%/year. About half of this growth was due to resource expansion (including expansion of cropland, irrigated area and fertilizer use) and about half to TFP growth. Growth in output per worker averaged 4.5% per year, which was driven by the increase in total factor productivity as well as growth in material inputs (especially fertilizer) per worker. The growth in output per agricultural worker had a major impact on reducing rural poverty and food insecurity (Timmer 2004).

By the early 1990s, modern crop varieties had been widely disseminated but further sources of technological progress were not immediately forthcoming. The agricultural research system was apparently not sufficiently developed to deliver post green-revolution technologies that could sustain productivity growth (Fuglie and Piggott 2006). Further, the redirection of national priorities from agriculture to manufacturing reduced investments in the sector. Although food crops continued to receive trade protection and price supports, Indonesia became a net importer of feed grains. The livestock sector severely contracted during the Asian Economic Crisis when the currency was devalued and feed imports became prohibitively expensive (Simatupang et al. 1999). During the "stagnation" period (1993–2001), agricultural output growth averaged only 1.5%/year and TFP growth only 0.6%/year. Resource expansion slowed markedly, due in part to fewer resources for fertilizer subsidies and estate crop schemes, the end of government-sponsored migration, and the contraction in livestock capital during the 1997–1998 Asian Financial Crisis.

By 1999 a new "Reform" government was in power and the economy gradually recovered from the Asian Financial Crisis. One outcome of the Crisis was liberalization of the agricultural sector: import restrictions on food crops were removed and fertilizer subsidies ended entirely (Fuglie and Piggott 2006). Other policy changes, such as the 1999 Forestry Law and the 2001 Local Autonomy Law, affected control and access to public lands for agricultural development (Contreras-Hermosilla and Fay 2005). Between 2002 and 2006, agricultural growth resumed a rapid pace of over 4%/year and TFP growth accounted for about 60% of this growth. While the labor force remained almost constant, land per worker and other inputs per worker each grew by about 0.6% per year. The growth in cropland per worker occurred entirely in the outer islands of Indonesia, while in Java total agricultural land area and average farm size declined (van der Eng 1996; BPSa 1993–2007). The land expansion in the outer islands was particularly pronounced for tree crop plantings. By expanding area in estate crops, farmers could make fuller and more productive use of their labor during the agricultural season. Farmers who settled previously forested or degraded forest lands may have initially emphasized subsistence food crop production in "swidden," or shifting agricultural systems but gradually established mixed food-tree cropping systems involving oil palm, rubber, cacao, coffee, and other perennials (Tomich et al. 2001; Belsky and Siebert 2003). The planting of tree crops was also a means of establishing recognized tenure over these newly opened lands (Otsuka et al. 2001). On Java, meanwhile, is it likely that agriculture also underwent intensification and diversification, with resources shifting from food and estate crops toward higher-valued horticulture, animal and aquaculture production.

Table 5 Output, input, and total factor productivity (TFP) indices for Indonesian agriculture

	Crops, animals and aquaculture		
	Output	Input	TFP
1961	100	100	100
1962	106	102	105
1963	101	102	99
1964	106	102	104
1965	108	105	102
1966	112	105	106
1967	108	104	103
1968	126	112	112
1969	130	108	120
1970	139	109	128
1971	143	111	128
1972	144	113	128
1973	156	113	137
1974	161	115	140
1975	161	116	139
1976	161	117	138
1977	169	120	140
1978	178	124	144
1979	186	127	146
1980	203	129	157
1981	218	135	161
1982	217	139	157
1983	234	147	159
1984	253	154	165
1985	262	156	168
1986	281	162	173
1987	285	170	168
1988	299	173	173
1989	313	178	176
1990	326	184	177
1991	332	188	177
1992	359	193	186
1993	362	197	184
1994	364	204	179
1995	397	209	190
1996	401	213	188
1997	386	212	182
1998	383	205	186
1999	392	205	192
2000	404	207	196
2001	412	210	196
2002	435	216	202
2003	464	219	212
2004	486	219	222
2005	495	224	221
2006	510	225	226
Average annual growth rates (%)			
1961–1970	3.66	0.96	2.70
1971–1980	3.78	1.67	2.10
1981–1990	4.74	3.54	1.20
1991–2000	2.16	1.18	0.98
2001–2006	3.86	1.43	2.43
1961–2006	3.62	1.80	1.82

Source: Author's estimates

Finally, Table 6 shows a steady but growing contribution of farmer education to productivity growth. Over the 1961–2006 period, the increase in average farmer education accounted for about 10% of the total growth in agricultural labor productivity. Moreover, the contribution of education to growth gradually increased over time. Since the early 1990s, agricultural labor has increased primarily in quality rather than quantity. It is likely that before the end of this decade agricultural employment in Indonesia will be in absolute decline. Raising the educational level of agricultural workers can offset this decline so that the transfer of labor from agriculture to other sectors will not be a drag on agricultural growth.

5 Conclusions

Growth accounting provides a useful tool for assessing and decomposing sources of economic growth. It requires more restrictions than regression analysis but avoids statistical problems arising from parametric estimation. The Tornqvist-Thiel index method minimizes aggregation biases that may arise in growth accounting when revenue and factor shares change over time but requires annual data on both quantities and prices. Quality changes in quantity series can be addressed through greater disaggregation of input and output categories and by constructing separate indices for quality changes in these categories over time.

I applied the Tornqvist-Thiel index method to examine sources of growth in Indonesian agriculture during 1961–2006. Improvements in the data series for Indonesian agriculture provide an opportunity to reassess the performance of this sector. The new estimates show that Indonesia achieved an annual growth rate in agricultural production of 3.6% over this period. Slightly less than half of this growth can be attributed to an expansion of conventional inputs (land, labor, capital and intermediate inputs) and the rest to improvement in total factor productivity. Productivity growth accelerated during the

Table 6 Sources of growth during episodes of indonesia's agricultural development

Stages	Instability 1961–1967	Green revolution 1968–1992	Stagnation 1993–2001	Liberalization 2002–2006	Whole period 1961–2006
Average annual growth rate (%)					
Total output	1.24	4.82	1.51	4.31	3.62
Total inputs	0.71	2.47	0.93	1.36	1.80
Total factor productivity (TFP)	0.54	2.35	0.58	2.95	1.82
Workers[a]	0.02	0.29	0.01	−0.28	0.13
Output/worker[a]	1.23	4.53	1.51	4.59	3.49
Land/worker[a]	0.15	0.21	0.24	0.61	0.26
Other inputs/worker[a]	0.35	1.62	0.37	0.62	1.09
Education	0.19	0.35	0.31	0.41	0.33
TFP	0.54	2.35	0.58	2.95	1.82

Source: Author's estimates

[a] The number of agricultural workers is measured in constant-quality units after adjusting for changes in the average schooling level of the agricultural labor force. Land includes land in crops and ponds, quality-weighted by type of land resource. "Other inputs" include all other measured inputs: animals, machinery, seed, feed, and fertilizer

"Green Revolution" period when modern varieties of food crops were widely disseminated, but stagnated during the 1990s. Productivity growth resumed in the early 2000s following recovery from the Asian Financial Crisis and liberalization of policies toward agriculture. It appears that commodity diversification, namely, allocating more agricultural resources to the production of higher-valued commodities as well as crops that make fuller use of farm labor, has been an important source of TFP growth in recent years. The private sector rather than the state appears to be the driving force behind the reemergence of growth in the sector. Over the course of 1961–2006, higher levels of schooling amongst the farm population account for about 10% of the growth in labor productivity. Continued improvement in the quality of labor can offset the projected decline in the size of the farm labor force.

In Indonesia's recent economic history, commodity diversification was probably as important a source of agricultural productivity growth as technological change. Farmers increased productivity by moving to more intensive production systems involving perennial tree crops, horticulture, animals and aquaculture. However, the gains from diversification were preceded by an impressive improvement in productivity of rice and other food staples. Having secured food security first may well have been a prerequisite for small-holder farmers to be willing to allocate more resources to producing non-staple commodities for the market.

Acknowledgments The author would like to thank the participants of a Workshop held at the Economic Research Service in Washington DC on March 15, 2007 and two anonymous reviewers for their helpful comments and suggestions. The views expressed in this paper are the author's own and not necessarily those of the U.S. Department of Agriculture.

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